FORGETTING IN AN ASSOCIATION MEMORY

Edward A. Feigenbaum*
University of California, Berkeley

and

Herbert A. Simon*
Carnegie Institute of Technology
Pittsburgh, Pennsylvania

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*Consultant, Computer Sciences Department
The RAND Corporation

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SUMMARY

A model of an association memory, the EPAM (Elementary Perceiver and Memorizer), is a learning system, a computer simulation of human verbal learning processes. No stored information in this memory is ever physically destroyed. Yet the behavior which we normally call forgetting occurs because of a loss of access (temporary or permanent) to information stored in a growing net of associations. In this system, forgetting occurs as a direct consequence of normal learning processes (i.e., forgetting is the result of the interference of items later learned with items learned earlier) without the postulation of a separate mechanism. Two experiments with human verbal learning are discussed, and the interference phenomena are explained in terms of the EPAM model.

FORGETTING IN AN ASSOCIATION MEMORY

Though the phenomenon of forgetting is an everyday and commonplace experience of human intelligent systems, it has been inadequately treated by theorists of intelligent systems (human and computer).

On the one hand, there is the stark behavioral fact that humans who were, at one point in time, able to respond in some particular way to some particular stimuli are, at a later time, no longer able to respond to those stimuli. On the other hand, there are the ever-intriguing experiences, shared by us all, that humans are able to recall stimuli whose age-in-memory is of the order of many years and that a person's techniques of association can be pressed into the service of retrieving "long lost" information from his memory (sometimes quite consciously!). Furthermore, some modern experiments [1], involving the implantation and stimulation of microelectrodes in the brain, have suggested that experiences far removed in time can be evoked in great informational detail by appropriate stimulation of brain tissue.

All of this suggests the possibility that forgetting is caused not by the physical destruction of information in the human memory, but by the misplacing -- the more or less temporary loss of access to -- information in memory. This possibility has been largely unexplored.

Instead, theories of forgetting have specified mechanisms for the destruction of information in memory, and these mechanisms are treated as separate from the mechanisms which account for the learning.

The purpose of this presentation is to explore the properties of a memory in which:

(a) information is stored in association with encodings of external stimulus configurations and with (internal) encodings already stored in the memory.

(b) no stored information is ever destroyed in the memory.

(c) what we normally call "forgetting" occurs as a direct consequence of the learning process which stores information in the memory (i.e., forgetting is the result of the interference of items later learned with items learned earlier).

The EPAM Learning System

EPAM (Elementary Perceiver and Memorizer) is a learning system which is intended to be a simulation of human verbal learning processes. The information processes of EPAM are realized as computer programs in the list-language IPL V. [2, 3]

The processes perform the following functions (among others):

(a) recognize an external stimulus as one about which some information has already been memorized.

(b) add new stimulus items to the memory by first building discriminations which allow the new item to be distinguished from stimuli previously learned.

(c) associate (internally) two stored items, x and y, by storing with x some cue information about y.

(d) respond to an external stimulus X with a response Y by first retrieving the cue to the response and then retrieving the response using the cue.

The memory structure of EPAM is the discrimination net. It is a tree at whose terminal points are stored images of encodings of external stimuli. At the nodes of the tree are stored tests which examine bits of the encodings of stimuli. The image of a stimulus is retrieved by sorting the encoding of the stimulus down through the tests of the net to the appropriate terminal. At any moment in the learning of a set of stimuli, the net contains just enough tests (roughly) to distinguish the stimuli already learned.

Information about a new stimulus being learned is added to the memory by first growing the net (i.e., adding discriminations). The new item is sorted to a terminal; a matching process produces a difference between the new item and the one stored at the terminal; a test is constructed to discriminate on this difference; the test is added to the net, thereby creating a terminal for the storage of the new information.

If there are two items, x and y, both of which have been learned in the net, association of y as the response to x is accomplished by storing a small amount of the y information with the image of x as a cue to the associated response. The system determines the amount of information to be stored as a cue -- by trial and error, as that quantity of information just sufficient to retrieve the response item from the net at the moment the association is being made.

EPAM responds to stimuli by recognizing a stimulus (sorting it in the net to its terminal), finding there the cue to the response, sorting the cue in the net, thereby retrieving the image

of the response. Not all the time will the response be retrieved by this process. If the cue lacks information which the discriminatory tests in the net need, then the response image is selected randomly from the undiscriminated subset. How this situation can come about is subsequently discussed.

This has been a very incomplete sketch of EPAM. More complete treatments are given in other places (Feigenbaum, 1959 [2], and 1961 [3]).

Interference and Forgetting

How can it happen that a response which EPAM was able to make correctly at some time will, at a later time, become lost? The answer lies in the fact that in EPAM the "bond" of association is indirect (a cue is sorted in the net of items) and is ever vulnerable to interruption by further learning.

As learning (say, in verbal learning experiments) proceeds, the discrimination net must grow to encompass the new items being learned. After new tests and branches are added to the net at some end point (displacing downward a response image which was located there), a cue which at some previous moment of association contained enough information to retrieve the response image becomes inadequate (in the sense that it lacks the information which the new tests wish to examine). This deficiency will not become apparent until the next opportunity arises for EPAM to attempt to make that response. In an attempt to respond with an inadequate cue, a wrong response image may be selected by the random mechanism described above (i.e., a response generalization

will occur). If the error can be detected (e.g., from feedback by the experimental apparatus in an experiment), the failure can be corrected by the process of adding more information about the correct response to the cue.

To summarize, learning which occurs after certain associations are made may interrupt these associations by growing the discrimination net so as to make inadequate the association cues which were previously adequate.

In psychological terms, the action of later learning in disturbing associations is called interference. The EPAM model gives a precise explanation of the phenomenon. Forgetting is a feature of the behavior of EPAM:

(a) because access to responses is lost in a growing memory net (but the loss need be only temporary if the difficulty is detected at some later time).

(b) as a consequence of normal learning processes without the specification of a separate forgetting mechanism.

(c) in spite of the fact that no memorized information is actually destroyed (by decay, overwrite, etc.).

Some Experimental Evidence

Consider two "classical" verbal learning experiments. In the first, a serial list of items is presented to a subject. When presented with an item the subject must respond with the next item on the list. The list is repeated until the subject can respond correctly to all items. In the other experiment, one such serial list is learned; then a second list is learned;

then a retest of the learning of the first list is made.

A feature of human behavior in the first experiment is this: the pattern of successes and failures on any particular item is irregular: a few successes, then a failure, then further successes, another failure, and so on. This phenomenon has been termed oscillation (by Hull [4]).

Characteristic of behavior in the second experiment is degradation of subjects' ability to give list A responses in the retest after the interpolated learning of the list B. This phenomenon has been termed retroactive inhibition.

EPAM, when used as subject in the same experiments, exhibits these phenomena. The explanation of these phenomena in EPAM terms is that both are caused by the interference of later learning with earlier learning. In the one-list experiment, this is intralist interference; in the two-list experiment, interlist interference. Both phenomena are caused by one and the same mechanism, interference, and are consequently intimately related. Oddly, this is an hypothesis which has received little attention in psychological learning theory.

Conclusion

We have presented a learning system which exhibits forgetting in verbal learning situations, even though no "forgetting mechanism" is explicitly postulated and no destruction of information in the memory takes place. This is not a hypothetical system but a fully-realized learning machine.

We do not wish to argue here that the interference process

described above is the only process of human forgetting. We are sympathetic to the view that there may be phenomena of forgetting which go beyond interference and which may involve an assumption of actual information loss. What we have demonstrated, however, is a physical learning mechanism, operating without the assumption of information loss, which forgets because it loses access to information in a growing memory net of associations. The demonstration may serve to clarify and sharpen some of the issues in the theory of forgetting in human and machine learning systems.

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